Using Phytotechnology to Remove Total Suspended Sediments and Polycyclic Aromatic Hydrocarbons in the Edwards Aquifer

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Abstract

The Edwards Aquifer of Central Texas is an environmentally-sensitive aquifer hosting several endangered species and one threatened species. Protection of the aquifer involves prevention of entry to the aquifer of sediments and/or pollutants carried with sediments. Sediments in terms of Total Suspended Solids (TSS) are regulated by Texas Commission on Environmental Quality's Edwards Aquifer Rules. Polycyclic Aromatic Hydrocarbons (PAHs) are one group of potential contaminants that may be present currently within the Edwards Aquifer area.

Phytotechnology, the use of plants in cleaning up harmful contaminants or preventing migration of sediment that could carry contaminants, is discussed in relation to two plant species - little bluestem (*Schizachyrium scoparium*) and switchgrass (*Panicum virgatum*). An objective of this research is to synthesize information on characteristics of these plant species into ways of using these species to contain TSS onsite or to remediate PAHs in the Edwards Aquifer, or alternatively to document why one or both species would not be appropriate for these uses.

*** Report Format and References Format are in the style of Agriculture Ecosystems & Environment.**

Keywords

Sediments; phytostabilization; phytoremediation; little bluestem; switchgrass; polycyclic aromatic hydrocarbons

1. Introduction

The Edwards Aquifer system in central Texas has as its westernmost boundary a hydrologic divide near Bracketville in Kinney County; this divide separates the aquifer from subsurface water flows going to the Rio Grande Basin. A hydrologic divide near Kyle in Hays County separates the southern Balcones Fault Zone portion of the aquifer from the northern Barton Springs segment of the aquifer [Texas Water Commission, 1993].

The Edwards Aquifer Recharge Zone is characterized by caves, sinkholes, faults, fractures, and other permeable geologic features that create avenues for surface water to enter the aquifer. The same system that enables recharge to occur also provides a greater potential for contamination [Texas Commission on Environmental Quality, 2005]. Rainfall is a primary method of transport of sediments and/or contaminants. Figure 1 depicts the Edwards Aquifer.

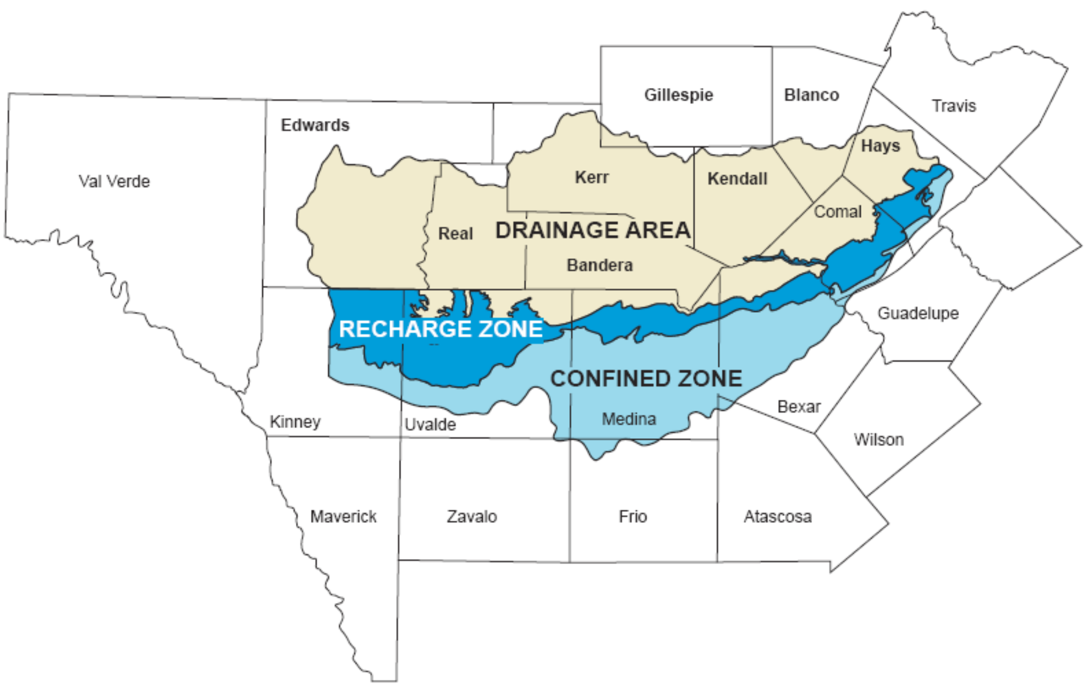

Figure 1 Edwards Aquifer Extent showing Drainage Area, Recharge Zone and Confined Zone This figure is extracted from the report "Analysis of Recharge and Recirculation Edwards Aquifer Phase 1" prepared for Edwards Aquifer Authority [Todd Engineers, 2004]

There is one threatened species within the Edwards Aquifer System, the San Marcos Salamander (*Eurycea nana*). Endangered species of the Edwards Aquifer system include the Fountain Darter (*Etheostoma fonticola*); Texas Blind Salamander (*Typhlomae rathbuni*) and the aquatic perennial grass Texas Wild Rice (*Zizania texana*). The Texas Blind Salamander is a cave-adapted species found only in Hays County. Texas Wild Rice needs fast-flowing water of high quality. The San Marcos Gambusia (*Gambusia georgei*) is listed as an endangered species but now is actually considered extinct since it has not been collected since 1982. This Gambusia previously was known to have existed in the upper reaches of the San Marcos River. [LBG Guyton Associates, 2004]

Endangered species of the aquifer also include the Comal Springs Riffle Beetle (*Heterelmis comalensis*) which lives in shallow riffles in spring runs and presumably in some karst voids - but its primary habitat is dependent on surface water flows. In the absence of data on water chemistry parameters that affect the Riffle Beetle, biologists assume that efforts to protect the beetle should strive to maintain temperature and dissolved oxygen within the historic range observed in the natural habitat for the species. [LBG Guyton Associates, 2004] Another endangered species is the Comal Springs Dryopid Beetle (*Stygoparnus comalensis*), a subterranean beetle living in karst voids near spring openings. Yet another endangered species is Peck's Cave Amphipod (*Stygobromus pecki*), a subterranean aquatic crustacean. Peck's Cave Amphipods have hydrophobic hairs on their undersides which maintain a thin bubble of hair through which gas exchange occurs. This exchange decreases as the level of dissolved oxygen in the water decreases [LBG Guyton Associates, 2004]. Given that decreased levels of oxygen in Edwards Aquifer surface water or in subterranean waters of karst voids may adversely affect one or more endangered species, one can understand why pollutants that tend to lower oxygen levels in water could be considered injurious to these species.

The presence of the Edwards Aquifer's endangered species sparked a years-long litigation that began with a lawsuit filed by the Sierra Club against the U.S. Secretary of the Interior and the U.S. Fish and Wildlife Service. The lawsuit was filed on behalf of endangered species of the Edwards Aquifer Area, under the Endangered Species Act. About four decades of negotiations among affected parties failed to yield a resolution of the dispute over proper management of the Edwards Aquifer. [Texas Water Commission, 1993]

In April 1992 the Texas Water Commission stated that the southern portion of the Edwards Aquifer met the legal requirements of an "underground river", and that water in an underground river is "state water" defined in Texas Water Code and therefore subject to Commission regulation. In September 1992 the Commission adopted rules setting limits on the amount of water that could be taken from the Edwards Aquifer. The Rules also established a procedural framework in which to develop a comprehensive regional water management plan. Two days later the rules were declared invalid by a state district court. However a federal district court in Midland issued a decision January 31, 1993 that if the State of Texas failed to enact a regulatory system by May 31, 1993 capable of protecting the species, then U.S. Fish and Wildlife Service may begin penalizing recipients of federal funds whose activities affect spring flow [Texas Water Commission, 1993]. Subsequent to this federal court decision the Texas Natural Resource Conservation Commission (formerly Texas Water Commission and now Texas Commission on Environmental Quality) developed the Edwards Aquifer Rules. The Rules have been revised to their present form.

Pollutants that tend to lower oxygen levels in water are a focus of the Texas Water Commission on Environmental Quality (TCEQ). Limiting such pollutants and limiting the amount of sediment generated by human activities on areas within the Edwards Recharge Zone are objectives of the TCEQ Edwards Aquifer Rules. These Rules prohibit new industrial discharges, confined animal feeding operations, sewage holding tanks and other activities. The Rules also regulate generation of sediment by regulating construction-related or post-construction activity on the recharge zone of the Edwards Aquifer having the potential for polluting the Edwards Aquifer and hydrologically connected surface streams. [Texas Commission on Environmental Quality, 2004].

The TCEQ Edwards Aquifer Rules also require persons or entities engaging in regulated activities to calculate the amount of Total Suspended Solids (TSS) that will result from their activities. The Rules are written generally enough to key into the TCEQ Technical Guidance for actual values of TSS removal that is required. This way of writing the Rules allows the TCEQ the flexibility to revise the Technical Guidance rather than to revise the Rules. Currently the

TCEQ Technical Guidance requires a TSS removal of 80% [Texas Commission on Environmental Quality, 2005].

Sediments in and of themselves affect water quality and thus may be harmful to endangered species of the Edwards Aquifer. Since sediments may carry one or more pollutants with them, sediments may pose a double hazard. Effective methodologies of dealing with sediments are likely needed in every region of the United States, but especially in environmentally sensitive areas such as the Edwards Aquifer. Phytotechnologies to reduce sediments may offer an attractive method by which to protect the Edwards Aquifer.

The term phytotechnology includes phytoremediation - the process of plants performing the function of cleaning up harmful contaminants from a site or containing harmful contaminants directly on a site (i.e., the site is already contaminated). However, in the case where one wishes to <u>prevent</u> migration of sediment that possibly could carry contaminants, or <u>prevent</u> migration of sediment because the sediment itself can be thought of as a contaminant (as in the case of the environmentally-sensitive Edwards Aquifer in Central Texas), phytotechnology also has a role to play. Plants can prevent migration of sediment to sensitive aquifers such as the Edwards Aquifer. Plants can immobilize sediment and/or contaminants attached to sediment particles via a process called "phytostabilization". Phytostabilization is defined as (1) immobilization of a contaminant in soil through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone of plants, and (2) the use of plants and plant roots to prevent contaminant migration via wind and water erosion, leaching, and soil dispersion [U.S. Environmental Protection Agency, 2000]. Hence the term phytostabilization justifiably describes the use of plants to prevent sediment transport to the Edwards Aquifer.

Phytoremediation, dealing with already-contaminated sites, is a term consisting of the Greek prefix phyto (plant) that attaches to the Latin root remedium (to correct or remove an evil) [Cunningham et al, 1996]. Remedial techniques apply information from agriculture, silviculture and horticulture to environmental problems [U.S. Environmental Protection Agency, 2000]. Some remedial techniques have been identified to remediate Polycyclic Aromatic Hydrocarbons (PAHS) from soil. Coal tar is a principal natural source of PAHs; some PAHs are also components of other automotive fluids [O'Connor, 1977]. Therefore PAHs might be found in urban areas or along highways. Certainly the Edwards Aquifer Area contains urban areas and highways.

The term "phytostabilization cover" is a noun that refers to a soil-sediment-plant unit; the plant component may be comprised of multiple species. This phytostabilization cover works to control erosion by minimizing bulk migration of the contaminated media. Phytosequestration mechanisms address the mobility of the contaminant itself. Therefore, phytostabilization covers are simply soil or sediment that are deliberately planted with vegetation selected specifically to control bulk soil migration and/or prevent contaminant migration through phytosequestration. In some instances, the same plant species can serve both the purpose of controlling bulk soil migration and the purpose of preventing contaminant migration [Interstate Technology and Guidance Regulatory Council, 2009].

This report specifically focuses on possible use of little bluestem (*Schizachyrium scoparium*) and switchgrass (*Panicum virgatum*) to control soil bulk migration (i.e., prevent sediment transport) and to prevent PAHs migration or to remove PAHs from areas overlying the Edwards Aquifer area. The subject species are briefly described as follows.

Switchgrass is a stout perennial grass with scaly creeping rhizomes and firm tough stems up to three meters tall. It grows in large or small clumps usually unbranched above the base. It is a native warm-season grass with a wide distribution on the North American continent due to its tolerance for either sandy or clayey soils and for a range of moisture conditions. Switchgrass has developed a number of ecotypes, some of which are quite different from the common lowland bunch grass [Gould, 1978]. Cultivated varieties as well as the original native species are available. Little bluestem (*Schizachyrium scoparium var. frequens*) is the variety of this grass that is most likely found in Central Texas, as the variety *divergens* is a shade-tolerant variety found primarily in East Texas. Little bluestem does not develop creeping rhizomes. The *frequens* variety is hairless or sparsely hairy. Little bluestem is a warm-season grass found throughout the state except in East Texas Pineywoods; it is a dominant of tall-grass prairies frequent on open rangeland, on rocky slopes, and in openings in woods [Gould, 1978].

At this point a discussion of sub-mechanisms of phytoremediation is necessary. The type of phytotechnology called phytoremediation is simply the use of plants to remediate contaminated soil, sediments, surface water, or groundwater. Phytoremediation includes sub-mechanisms of phytovolatilization, rhizodegradation, phytoextraction and phytodegradation

[Interstate Technology and Guidance Regulatory Council, 2009]. These are sub-mechanisms used by the plants, but the terms are also applied to describe the type of phytotechnology used on a project site. As per the Interstate Technology and Guidance Regulatory Council's Glossary, phytovolatilization is defined as the uptake and subsequent transpiration of volatile contaminants through the plant leaves. The definition of rhizodegradation is biodegradation of organics by the soil organisms. Phytoextraction is defined as the uptake and accumulation of inorganic elements into the plant tissues. The definition of phytodegradation is the process where plant-produced enzymes break down dissolved organic contaminants that are in the plant through the uptake of water [Interstate Technology and Guidance Regulatory Council, 2009, Appendix E – Glossary].

The term phytohydraulics describes the way in which the transpiration stream (i.e., transport through a plant from roots up to branches, stems and leaves via xylem tissue) can transport not only water and dissolved mineral nutrients for benefit of the plant, but also can transport contaminants with this water. Once the contaminants are in the upper reaches of the plant, the contaminants may then either phytovolatilize (exit the plant in the gaseous phase via stomates of the leaves) or phytodegrade (be chemically transformed) or a combination [Interstate Technology and Guidance Regulatory Council, 2009]. The evapotranspiration rate of particular plant species determine to a large degree how effective that species can be in performing phytohydraulics as a remediative action. Evapotranspiration rates of grasses commonly are expressed in terms of inches per year or millimeters per day, whereas many tree species evapotranspirate hundreds of gallons per day per tree [Interstate Technology and Guidance Regulatory Council, 2009, Appendix C]. One can easily see that phytohydraulics are of major importance in tree species, but less so in grass species.

Polycyclic aromatic hydrocarbon (PAH) is the name given to a group of numerous chemicals with large molecules; they are generally recalcitrant contaminants. Nevertheless phytoremediaton projects dealing with successful removal or treatment of PAHs have been used, tested on pilot-scale or field-scale basis, studied and described in scientific literature. According to an inventory of case study information collected during the International Phytoremediaton Conference, 2007 in Denver, Colorado, phytoremediative mechanisms were used to remove four chemicals simultaneously present at approximately twelve sites [Interstate Technology and Regulatory Council, 2009, Appendix C].

An objective of this research is to find characteristics of the two plant species and synthesize that information into ways of using these species to contain sediments onsite or to remediate PAHs, or alternatively to document why one or both species would not be appropriate for these uses. The perspective is that of applying the information to possible use over the Edwards Aquifer area.

2. Methods

The literature search had two goals. The first goal was to find information on characteristics of little bluestem and characteristics of switchgrass that may make them viable candidates for efficient removal of sediments in the specific context of the Edwards Aquifer. These characteristics may be physiologic, morphologic or agronomic in nature. An example is high rain interception capability - the ability of plants to intercept a significant portion of rain (or irrigation) on their leaf surfaces. When rain interception capacity is exceeded, surface runoff and/or shallow infiltration into soil occur, as illustrated in Figure 2.

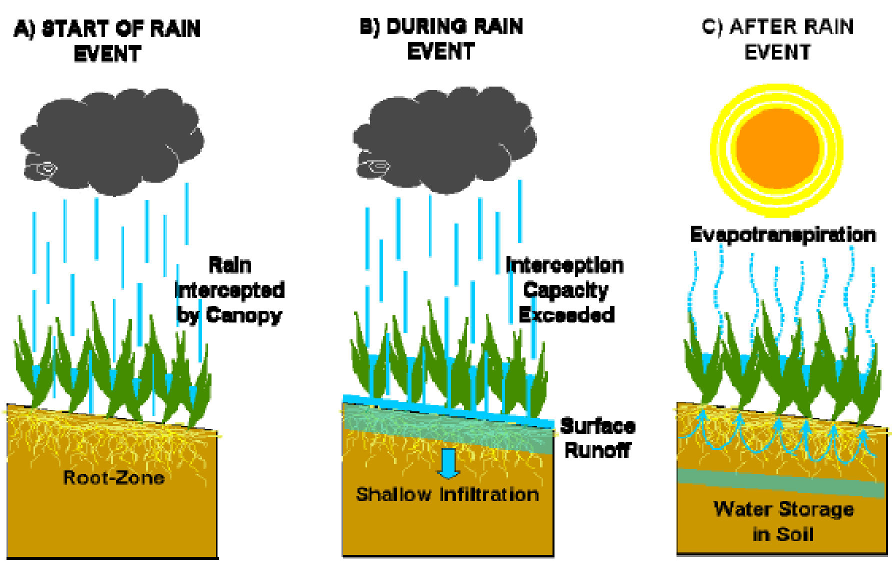

Figure 2 Illustration of Plant Rainfall Interception Capacity

This figure is extracted from the report “Phytotechnology Technical and Regulatory Guidance and Decision Trees” [Interstate Technical and Regulatory Council, 2009].

The second goal of the literature search was to find information on characteristics of little bluestem and switchgrass that may make them viable candidates for efficient removal of PAHs in the specific context of the Edwards Aquifer. These may likewise be physiologic, morphologic or agronomic characteristics. Examples may be high rhizodegradation capability (which often is enhanced by interrelations between microflora and plant roots and/or by root exudates), or absorption by roots and subsequent phytosequestration. In general, most organic contaminants undergo some degree of chemical transformation in the cells of plants before being sequestered in vacuoles of individual plant cells or bound to insoluble cellular structures such as lignin [Salt et al, 1998].

A particular plant characteristic may make a species a viable candidate both for efficient removal of sediments from runoff and for efficient removal of PAHs. Such a characteristic is rain interception capacity. Rain interception capacity is important to whether sediment is captured and held onsite versus transported by runoff to offsite locations. A delay in runoff occurrence necessarily delays the potential for sediment transport in the runoff. Rain interception capacity is also important to remediation of contaminants such as PAHs. If reducing contaminant mobility is the primary objective, the main focus should be on rain interception and/or groundwater uptake and subsequent evapotranspiration from both processes [Interstate Technology and Regulatory Council, 2009].

The literature search uncovered far more references for switchgrass than for little bluestem, both in terms of sediment removal and in terms of PAH removal. The number of references dealing with switchgrass may be due to the research performed on switchgrass associated with its potential for use as biofuel. The same switchgrass characteristic that lends itself to use as biofuel - high fiber cellulose content - also makes the stems sturdy, enabling the actual physical entrapment of sediment by the plant. In addition to high cellulose content, another factor that makes stems sturdy is the amount of parenchyma tissue in a plant. Parenchyma cells have thick lignified walls that can form long fibers which are a source of strength to mature stems [McMahon et al, 2007]. Following from this line of reasoning, this author determined that information needed was measurements of the biomechanical properties of grass stems - specifically modulus of elasticity which would indicate whether the grass will be bent over by water or will hold and pond water.

3. Results

3.1. Rain Interception Capacity

Since a plant species' rain interception capacity is important to both sediment fate and contaminant remediation, the rain interception capacities for the two subject plants are discussed first, prior to separate discussions about sediment fate or PAH remediation. Rain interception capacities for both tree and groundcover systems are often reported as a percentage of the total precipitation event that is captured by the plant canopy. Therefore, these rain interception capacity values are highly dependent on the duration and magnitude of the precipitation event [Interstate Technology and Regulatory Guidance Council, 2009]. This explains why most rain interception capacity values include a notation regarding the associated precipitation event or rate of irrigation application. The rain interception capacity of little bluestem ranges from 50 – 60 % with water applied at a rate of ½ inch in 30 minutes. Switchgrass rain interception capacity is 57% at that same rate of water application [Interstate Technology and Regulatory Guidance Council, 2009].

3.2 Switchgrass and little bluestem: Efficiency in Retaining Sediments Onsite

References pertaining to sediment fate tend to fall into two categories. For purposes of this paper, the term Category 1 articles will be applied to articles written from the perspective of soil and water conservation; these articles usually measure and document findings out in the field. The term Category 2 articles will be applied to articles written with the objective of comparing various grasses for removal of nutrients and sediments; usually the authors strive to better understand those morphologic characteristics of grasses that make the grasses suitable for vegetative barriers.

At this point a brief discussion of the terms “vegetative filter strip” and “vegetative barrier” is in order. Although the two terms have at times been used interchangeably, actually each term should be descriptive of its function. The function of a vegetative filter strip is to control water-caused erosion; the objective is to produce uniform shallow overland flow across the filter strip. Ostensibly the uniform shallow overland flow allows biological filtration of pollutants from the runoff as the runoff flows through the strip. However, what often happens is that, rather than allowing the runoff to flow through, the vegetation actually slows the runoff and physically traps sediment suspended in the runoff. Thus many “vegetative filter strips” should be more properly called “vegetative barriers”.

Category 1 articles tend to refer to vegetative barriers (rather than vegetative filter strips) and may further subcategorize these vegetative barriers as “contour grass hedges” aka “grass hedges” or “grass hedgerows” especially when the paper discusses the use of stiff-stemmed grasses such as vetiver or switchgrass as vegetative barriers. Category 2 articles sometimes use the term “vegetative filter strip” even when the gist of the article suggests that functionally what is happening is the “vegetative barrier” phenomenon. This paper’s Discussion retains whatever terms were used by the authors of the articles.

When the goal is to reduce Total Suspended Solids (TSS), a traditional approach has been to allow erosion and to allow sediment transport - then trap the generated sediment. A different approach involves a sediment source control. The objective is to target a sensitive area and use vegetation on that area that minimizes erosion - such as a biomass crop (switch grass) [Geza et al, 2009]. The Grass Hedge Work Group, comprised of USDA ARS and USDA NRCA staff and researchers from universities and the National Academy of Sciences, defined characteristics that are essential for grass hedges. These characteristics are stiff stems that will not bend over when water flows through them, and sufficiently dense tillering to trap residues and retard water flow. The work group identified switch grass as a possible candidate for use in grass hedges throughout much of the United States [Kemper et al, 1992].

Since stiff stems that will not bend over when water flows through them is a characteristic essential for grass hedges, the modulus of elasticity E is an important biomechanical parameter. Modulus of Elasticity E values for little bluestem are not available but the modulus of elasticity E of switchgrass at three growth stages (vegetative stems, green internodes and dry internodes) has been researched and documented at 0.73 GPa, 2.9 GPa, and 8.5 GPa respectively [Dunn et al, 1996].

Put into perspective, the switchgrass modulus of elasticity E of 8.5 GPa at dry internodes growth stage is similar to (dry) black cottonwood E of 8.7 GPa [Dunn et al, 1996]. The switchgrass E of 2.9 GPa at its green internodes growth stage compares favorably to E values of hard manufactured materials. For instance, switchgrass E of 2.9 GPa is comparable to modulus of elasticity E values of polystyrene that range from 2.6 to 3.4 GPa, or to E values of rigid polyvinyl chloride (PVC) pipe that range from 2.1 to 3.4 GPa [Dunn et al, 1996].

Another important capability of plants is that they regenerate themselves - in the event of failure to contain ponded water under a significant rainfall event, plants can simply regrow and begin to pond water again. The hard materials with modulus of elasticity E comparable to switchgrass (polystyrene and rigid PVC pipe) obviously cannot regenerate in the event of failure. The plants' capability to regenerate give plants the advantage in the context of containing water under significant rainfall events.

The concept of a grass hedge that is capable of ponding water can best be described graphically. Figure 3 is a diagram showing initial stage and mature stage of grass hedge on a hillside. Note the ponded water and how the mature grass cumulates more and more sediment, so that over time the grass hedge forms a contoured bench similar to what would otherwise require heavy soil-moving equipment to accomplish.

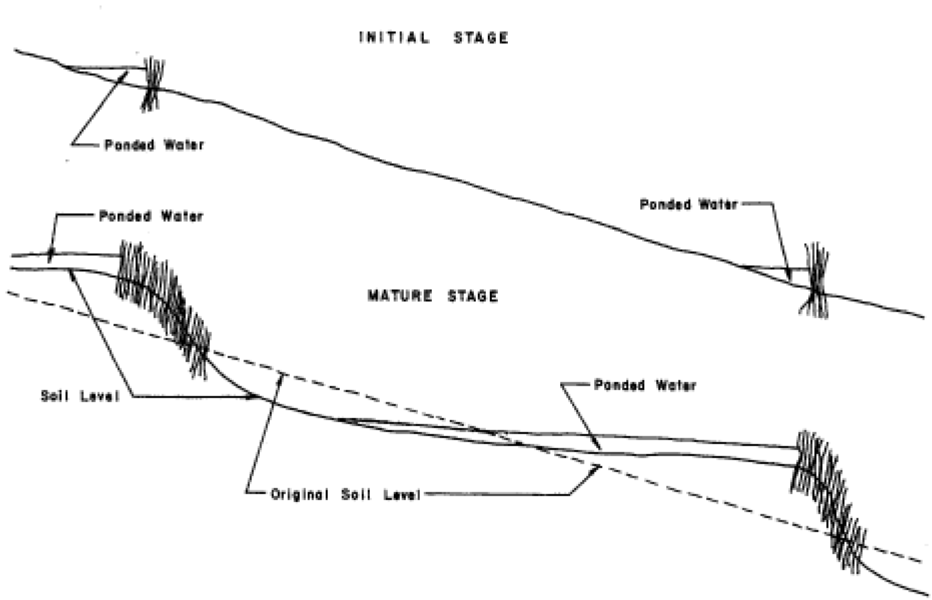

Figure 3. How Grass Hedges pond more water over time from initial stage to mature stage

Figure 3 is from “Hedging Against Erosion”, Journal of Soil and Water Conservation Volume 4, 284 - 288 [Kemper et al, 1992].

Most of the sediment that is trapped above the hedge is deposited because it has sufficient settling time in the ponded flow, not because it was unable to pass through the voids in the grass [Meyer et al, 1995]. This is an important distinction to make in understanding how these grass hedges work. Rather than filter sediments, the grass hedges pond water as would detention basins, giving sediments time in which to settle.

Establishing a mature perennial grass hedge takes two to three years [Kemper et al, 1992] but there appears to be potential for major long-term benefits from causing sediment deposition upslope of grass hedges. Sediment is kept near its point of origin and land slope between the hedges is gradually reduced as more sediment is deposited. Over time, the grass hedge “benches” become flatter and broader so that more runoff water is temporarily ponded, resulting in more intake opportunity time, more infiltration and less runoff [Kemper et al, 1992]. USDA

Agricultural Research Service scientists found that hedges of ‘Alamo’ switchgrass grow several feet high, with dense tillering and deep rooting [Kemper et al, 1992].

In areas of sediment accumulation (i.e., at the base of the grass hedge) the coarser sediment is preferentially retained [Kemper et al, 1992]. Other research confirms that the coarser sediment is preferentially retained. Meyer et al found that grasses that physically trap sediment via ponding action are effective and that hedges of switchgrass caused backwater depths of up to 400 mm (15.75 inches), trapping more than 90% of sediment coarser than 125µm. With these dense switchgrass hedges, the fraction of sediment trapped decreased only a few percent as flow doubled. However, the finer particles are not as efficiently removed as are the coarse particles [Meyer et al, 1995].

Researchers found the effect of switchgrass grass filter strips on sediment was at least a 66% removal during only a 127-day sampling period [Rankins et al, 2001]. These researchers compared characteristics of several grasses and noted that big bluestem, eastern grama, switchgrass and tall fescue each are effective. However, switchgrass has an added benefit in that, of the four grasses studied, it is the most tolerant to herbicide drift [Rankins et al, 2001]. Such drift could occur in rural areas with unimpeded wind; therefore a grass that survives exposure to herbicide would not need replacement at the associated replacement cost.

Research conducted over a longer sampling period includes a report from researchers who positioned a multispecies riparian buffer to intercept runoff and sediment from an adjacent 2.8 hectare (6.9 acre) hill slope in Pottawattomie County, Iowa, near Treynor. The switchgrass zone of the buffer measured 0.13 hectare (0.3 acre) and was located nearest the cropped area (i.e., this switchgrass zone was the first zone encountered by sediment generated from the area). The switchgrass was mowed the first year to help control weed competition and had established itself within two years. During a subsequent three-year period, data were taken. The 0.13 hectares of switchgrass trapped at least 14.5 Mg sediment per hectare of the contributing area (6.5 tons per acre) [Tomer et al, 2007]. On an annual mean basis, this is 4.8 Mg sediment per hectare of contributing area.

Other research conducted over a long sampling period includes an eight-year study at a site near Holly Springs, Mississippi. The research involved 0.1 hectare contour-planted plots with and without one-meter wide switchgrass hedges at their lower ends. The decrease in sediment yield was 25 to 28% [Dabney et al, 2012]. The soils at this Mississippi site, being fine-silty mixed silt loams, were of fine textures that are not as efficiently trapped by switchgrass as are coarser sediments, yet this decrease in sediment yield was still observed.

A study conducted at USDA's National Soil Tilth Laboratory near Council Bluff, Iowa, consisted of rainfall simulation over 0.72 meter wide vegetative strips of switchgrass that had been established for six years, located generally along contour. Soil loss decreased by 53% for plots under no-till conditions with corn residue retained and with the presence of switchgrass hedges. Soil loss decreased by 57% for plots under tilled conditions with corn residue retained and with the presence of switchgrass hedges, and soil loss decreased by 63% for plots under tilled conditions with corn residue retained and with the presence of switchgrass hedges [Gilley et al, 2000]. Soil was a fine-silty mixed soil that had developed on a deep loessal mantle overlying glacial till. Again, finer soil results in slightly less effectiveness by the grass hedges.

Another factor affecting the ability of switchgrass in trapping sediment *may* be the ratio of drainage contributing area to the vegetated area. The Pottawottamie County Iowa study showing an annual removal of 4.8 Mg sediment per hectare of contributing area had a contributing area of 2.8 hectares and employed 0.13 hectare of switchgrass. This ratio is approximately 21:1 which is comparable to a 20:1 ratio in another study in Story County, Iowa. This study evaluated test plots under simulated rainfall conditions. These filter strips were of two sizes: six meters wide corresponding to a ratio of 20:1 drainage area to vegetative strip area, and three meters wide corresponding to a ratio of 40:1 drainage area to vegetative strip area. The 40:1 strip removed 78% of incoming sediment and the 20:1 strip removed 69% of incoming sediment [Lee and Isenhart, 1990]. Here, the 78% sediment removal from surface water closely approximates the 80% rate of TSS removal that is required by Texas Commission on Environmental Quality for locations within the Edwards Aquifer area.

However, the Story County rainfall simulation results bring up an interesting point in that the narrower vegetated area actually performed better than the wide vegetated area, despite the overall ratio between drainage area and vegetated area. One can surmise that – at least on an individual rainfall event basis - the wider switchgrass area actually cuts efficiency of the switchgrass because any room for ponding is taken up by the wider strip's extra three meters of vegetation uphill. This may be borne out by the USDA rainfall simulation study at Council Bluff, Iowa, where the narrow (0.72 meter wide) strips of switchgrass almost eliminated runoff from storms of the magnitude 64 mm per hour for the duration of one hour [Gilley et al, 2000]. A 64 mm per hour storm corresponds to a 2.52 inch storm per hour, which equals a one-hour duration rainstorm of approximately the 10-year frequency in the Texas Edwards Aquifer Area [United States Geological Survey, 2004. Figure 30].

An aspect to switchgrass is that (like many grasses) it is a C_4 plant. Plant physiologists have identified C_4 plants as those that utilize the C4 cycle, or Hatch-Slack cycle of photosynthesis, in which the first products after CO_2 fixation are four-carbon molecules (as opposed to three-carbon molecules produced by the C3 cycle of C_3 plants). These C_4 plants are more efficient at photosynthesizing food in conditions of drought and/or temperatures exceeding 100 degrees Fahrenheit. [McMahon et al, 2007]. This makes C_4 plants more suited to heat and potential drought conditions of Central Texas than are C_3 plants.

3.3 Switchgrass and little bluestem: Ability to Perform Phytoremediation on Polycyclic Aromatic Hydrocarbons

References dealing with phytoremediative capabilities of switchgrass and/or little bluestem tend to focus on the particular mechanisms used by the plants, in which switchgrass and/or little bluestem are cited as examples of one or more mechanism. Some articles specifically address the ability of switchgrass and/or little bluestem, whether singly or in combination with other grasses, to phytoremediate Polycyclic Aromatic Hydrocarbons (PAHs). Research on switchgrass shows that switchgrass changes soil properties of the soil below and in the vicinity. Switchgrass increases saturated soil conductivity and increases soil macro porosity [Rachman et al, 2001]. When a plant alters the chemical or physical nature of the matrix to sequester the contaminant in the matrix, the plant is performing a function of phytostabilization

[Cunningham et al, 1996]. In altering soil properties, switchgrass appears to perform the function of phytostabilization.

In general, BTEX compounds are rapidly degraded in the presence of oxygen [Gemida et al, 2002]. Switchgrass, that increases macroporosity of the soil (i.e., large pores that contain air or water when available), could be a good rhizodegrader of BTEX compounds because these compounds are relatively soluble, making them available in dissolved soil water of macro pores. The chemicals are exposed to the oxygen contained in the macro pores, making the chemicals subject to this rapid rhizodegradation.

Rhizodegradation, also known as plant-assisted bioremediation, is the likely mechanism for removal of PAHs from soil; uptake of these large molecules into the plant is improbable [Hutchison et al, 2003]. Further, these PAHs are not degraded directly by the plants, but indirectly via plant release of enzymes into the soil. These plant enzymes catalyze certain chemical reactions that transform the contaminants [Gemida et al, 2002]. Plants also interact with microorganisms in the rhizosphere. Root exudates may contain organic compounds that serve as carbon and nitrogen sources for growth and survival of microorganisms that are capable of degrading pollutants [Alkorta, 2001], often forming symbiotic biofilms on the roots. Rhizospheric microorganisms may accelerate remediation processes by volatilizing organics such as PAHs [Alkorta, 2001]. BTEX also can serve as primary electron donor for a wide variety of soil bacteria [Gemida et al, 2002], furthering the possibility of bacterially-accelerated rhizodegradation of these PAHs.

Additionally, a possible explanation as to why switchgrass, little bluestem and other deep-rooted prairie grasses are effective in removing PAHs from contaminated soil via stimulation of rhizosphere micro flora may lie in root structure. It has been suggested [April and Sims, 1990] that the fibrous roots of these grasses offer more root surface for colonization by micro flora that enhance degradation of PAHs. Grasses have very highly branched root systems that are fibrous and explore a large volume of soil, particularly in the microspores [Hutchinson et al, 2003].

Both little bluestem and switchgrass are identified as plants that phytoremediate petroleum hydrocarbons [Gemida et al] and case studies have been performed for both species. Little bluestem was included in phytoremediation demonstration plots at the Allen Park Clay Mine Landfill in Allen Park, Minnesota. These demonstration plots were implemented prior to implementation of full-scale phytoremediation efforts at the Rouge Manufacturing Complex in Dearborn, Michigan. Initial concentration of PAHs in the demonstration plots was 130 mg per kg of soil. The treatment reached 60-65% reduction in soil PAH content after three seasons. [United States Environmental Protection Agency, 2011]. Little bluestem was also tested at the 26-acre site at British Petroleum Wood River Refinery, on Wood River in Illinois. Various petroleum and additive wastes were treated by a variety of trees and grasses. Laboratory pilot tests identified those species best suited for the site and subsequent field studies provided information on the impact of seasonal changes and environmental factors that could not be observed during lab tests.

Switchgrass was planted over stabilized waste oil and a foot of clean fill, with poplar trees surrounding the site, in treating BTEX at Greiner's Lagoon, Ballville Township, Ohio. The total cost of the remedy was $719,000; had the waste oil been handled and a Type C cap placed over it as per Resource Conservation and Recovery Act, the cost would have been $5.6 million. [United States Environmental Protection Agency, 2011]. These case studies deal with large contaminated sites, but the mechanisms of phytotechnology at work can be transferred to smaller sites.

Pradhan et al assessed the ability of switchgrass and little bluestem to phytoremediate during a six-month laboratory study in a small greenhouse. The researchers used two contaminated soils and three plant species (alfalfa, little bluestem and switchgrass). The individual BTEX contaminants as well as Total PAHs were measured in the study. Soil A was not pretreated and had an initial Total PAH concentration of 200 mg/kg of soil. In this soil switchgrass attained a soil reduction of Total PAHs of 56.9% and little bluestem attained a soil reduction in PAHs of 47.4%. Soil B had an initial total PAH concentration of about 1,000 mg PAH per kg of soil. Soil B was pretreated to 100 mg PAH per kg of soil prior to phytoremediation. In this pretreated Soil B, switch grass attained a soil reduction in PAHs of only 9.3 % and little bluestem attained a soil reduction in PAHs of only 8 % [Pradhan et al, 1998]. This suggests that the grasses need a certain minimum level of PAH contaminant in order to remove that contaminant – a counterintuitive judgment until one remembers that BTEX compounds also can serve as primary electron donor for a wide variety of soil bacteria – bacteria that accelerate rhizodegradation processes.

Other researchers evaluated the ability of switchgrass and other plant species to phytoremediate soil from a manufactured gas plant site with high concentrations of recalcitrant Polycyclic Aromatic Hydrocarbons (PAHs). These researchers found that switchgrass degraded Total PAHs by 24% after the first three months of phytoremediation, by 44% after nine months, and by 68% after twelve months. [Cofield et al, 2007]. The initial soil concentration exceeded 2,600 mg Total PAH per kg of soil. Apparently this initial PAH concentration satisfied the grass-microorganism symbiosm's requirement for electron donations from the chemicals and it appears that rhizodegradation played a major role in this PAH reduction.

Another important finding of the Cofield study is that PAHs concentrated almost exclusively in the roots, rather than in shoots. Therefore not only was the sub mechanism of rhizodegradation in operation, but phytosequestration as well. Phytosequestration of PAHs in the plant roots likely allays environmental concern about wildlife ingesting the aboveground vegetation.

Obviously there are other potential environmental concerns involved with phytoremediation, such as effect of contaminants on microbial species of the root zone and proper disposal of plant tissues containing high amounts of contaminants. However, sequestration of PAHs in roots means that aboveground tissues are not affected and do not require disposal. Further, there are phyto-based processes that have been demonstrated to reduce bioavailability to humans and to the environment [Cunningham et al, 1996]. Examples of these processes are humification, lignification and irreversible binding. Humification is defined as incorporation of the contaminants into soil humus resulting in lower bioavailability.

Lignification is defined as that situation when toxic components become irreversibly trapped in plant cell wall constituents (lignin). Irreversible binding refers to the situation where, over time, compounds become increasingly unavailable due to binding into soil [Cunningham et al, 1996].

Further clarification of terms is helpful. Humification involves incorporation of contaminants into soil humus. Humus by definition is “the more or less stable fraction of the soil organic matter remaining after the major portion of plant and animal residues has decomposed”. Humus is also described as a complex, amorphous, colloidal substance that remains after decomposition and that is resistant to further decomposition [McMahon et al, 2007]. The resistance of humus to further decomposition explains its low bioavailability. Some researchers list humification under the phytodecontamination category, as regulatory analytical results suggest. However, others list humification as a phytostabilization process because certain analytical techniques, including some forms of high-temperature thermal extraction and supercritical fluid extraction, have been shown to release some of the bound residues [Cunningham et al, 1996].

Regarding lignification, the contaminants deposited in lignin seem to be relatively biologically inert and are considered “degraded” because they do not appear in regulatory extraction protocols. Contaminants deposited in the lignin fraction of roots require further research to clarify whether these contaminants are released upon the death and decay of the root, and if so, to what extent [Cunningham et al, 1996].

4. Discussion

The literature search yielded a paucity of data on case studies or field trials of phytotechnology in general, in the state of Texas. Specifically, there is a paucity of data on little bluestem’s ability to affect sediment fate in terms of whether or not that sediment is contained on-site (i.e., removed from surface water runoff). There is also a lack of studies performed in Texas that deal with either of the two subject plant species in regard to their ability to remove sediments from surface runoff, with the exception of the Alamo switchgrass hedge near Big Spring, Texas which offers valuable insights into both wind and water erosion capabilities of switchgrass.

Lack of data may explain why phytotechnology has not been implemented to date on locations over the Edwards Aquifer. What is implemented are Best Management Practices listed below.

Table 3-1 Summary of Permanent Structural BMPs with Verified Performance

Permanent Structural BMP	TSS removal efficiency (%)	Drainage Area Limit		Slope Range/Limitation		Amount of land required	Maintenance requirements
		Small (less than 10 ac)	Large (10+ acres)	2 – 6 %	20 % or less		
Retention/Irrigation	100		☼	☼		Large (irrigation)	High
Extended Detention Basin	75		1 ☼	☼		Moderate	Low to Medium
Grassy Swales	70	☼		☼		Large	Low to Medium
Vegetative Filter Strips	85	☼			☼	Large	Low
Sand Filter Systems	89	☼				Moderate	Medium
AquaLogic Cartridge System	95	☼				Moderate	High
Wet Basins	93		2 ☼	☼		Large	Medium to High
Constructed Wetlands	93		☼	☼		Large	Medium to High
Bioretention	89	☼				Small	Medium to High
Permeable Concrete	89-100	☼		☼		Small	Medium

Note: 1. Maximum drainage area for this BMP is 100 acres
2. Maximum drainage area is 1 mi^2

Table 1 Summary of Permanent Structural BMPs with Verified Performance

Table 1 is extracted directly from Texas Commission on Environmental Quality "Complying with the Edwards Aquifer Rules Technical Guidance on Best Management Practices" [Texas Commission on Environmental Quality, 2005]

Material for Chapter 3 of TCEQ's document "Complying with the Edwards Aquifer Rules Technical Guidance on Best Management Practices", RG-348, commonly referred to as

TCEQ Edwards Aquifer Technical Guidance Manual, is derived primarily from storm water guidance documents developed and adopted by other regulatory bodies. Primary sources include the Lower Colorado River Authority, North Central Texas Council of Governments, the City of Austin and others [Texas Commission on Environmental Quality, 2005].

The focus on the traditional approach of allowing erosion, then dealing with the sediment that is generated by that erosion, is apparent within this TCEQ Edwards Aquifer Technical Guidance Manual. There appears to be little recognition within the manual that the type of vegetation (i.e., particular plant species) makes any difference to efficiency of TSS removal from surface water. For instance, page 3-10 of the 2005 edition of the manual, in discussing grassy swales, states "Pollutant removal capability is related to channel dimensions, longitudinal slope, and amount of vegetation." Selection of plant species is not mentioned within that sentence. Nor is plant species selection mentioned in section 3.4.5 which deals with the Grassy Swales Best Management Practice. Oddly enough the definition for Grassy Swale section 3.4.5 does not specify or mandate that the plants in the swale should actually be grasses.

Section 3.2.4 of the TCEQ Edwards Aquifer Technical Guidance Manual, which deals with the Vegetative Filter Strips Best Management Practices states "Filter strips, also known as vegetated buffer strips, are vegetated sections of land similar to grassy swales, except they are essentially flat with low slopes, and are designed only to accept runoff as overland sheet flow." No mention of specific plant species selection appears - and certainly that sentence excludes any consideration of ponding, or of a hedge effect or vegetative barrier effect. Section 3.2.4 of the manual generally addresses type of vegetation for the Vegetative Filter Strip Best Management Practice with this statement: "To avoid flow channelization and maintain performance, a filter strip should contain dense vegetation with a mix of erosion resistant, soil binding species."

The TCEQ Edwards Aquifer Technical Guidance Manual does contain a detailed description of vegetation in the section dealing with extended detention basins. Here switchgrass is listed as a wet tolerant species and recommended for planting in detention basins. After finding that switchgrass can detain runoff effectively behind grass hedges, this author asserts that a series of switchgrass hedges could serve as a series of small detentions, performing similarly to a large detention basin. The TCEQ Edwards Aquifer Technical Guidance Manual strengthens that assertion (albeit perhaps inadvertently) by its inclusion of switchgrass as a recommended planting for detention. The assertion is further strengthened by the findings on modulus of elasticity E of switchgrass, which compares favorably to modulus of elasticity E values of polystyrene plastic and rigid PVC [Dunn et al, 1996]. In addition to having E values comparable to those of plastics, switchgrass can simply regrow should it fail to pond water under certain rainfall events.

In February 2008 TCEQ developed an Interoffice Memorandum through its Remediation Division; a copy of this Memorandum is included as Appendix A. This Memorandum states that agency Remediation leaders agree that the Interstate Technology and Regulatory Council's "Phytotechnology Technical and Regulatory Guidance Document" is appropriate and that they commit to using the document to the maximum extent feasible. Whatever the reasons for why phytotechnology has not been implemented to date on locations over the Edwards Aquifer, this TCEQ Memorandum clearly indicates that TCEQ leadership commits to using phytotechnology. Presumably the area overlying the Edwards Aquifer is no exception to this commitment.

Despite lack of data on little bluestem, the literature search does provide important clues as to how to possibly implement switchgrass hedges or switchgrass vegetative barriers on areas overlying the Edwards Aquifer Area. For purposes of removing Total Suspended Solids from surface runoff, switchgrass has been shown to be effective. Rankins et al found that switchgrass effect on sediment was at least a 66% removal during only a 127-day sampling period [Rankins et al, 2001]. Lee and Isenhart found that switchgrass achieved a removal of 78% of incoming sediment [Lee and Isenhart, 1999]. This closely approaches the 80% rate of TSS removal that is required by TCEQ for locations over the Edwards Aquifer.

Data suggesting that coarser particles are preferentially retained by switchgrass hedges allows transference of information gathered from other locations to locations over the Edwards Aquifer area for purposes of preventing sediment transport into the sensitive aquifer. Switchgrass hedges have been found to trap more than 90% of sediment coarser than 125µm, which is a particle size that falls between the #100 and #140 soil sieve spacing. Site-specific soil assessments could be performed to determine if particular Edwards Aquifer soils contain particles that fall within this range. Additionally, field studies could be performed that combine switchgrass with winter fescue (fescue forms a mat between switchgrass stems and thus may increase impenetrability of the grasshedge).

In regards to PAH-phytoremediative capabilities of the two subject plant species, Germida et al stated that both little bluestem and switchgrass are identified as plants that phytoremediate petroleum hydrocarbons. There exist case studies dealing with PAH phytoremediation performed by both of these species. Gemida et al state that BTEX compounds are rapidly degraded in the presence of oxygen. References document switchgrass' ability to increase the soil's number of macro pores (which contain oxygen). This increased oxygen in an increased number of macro pores may give switchgrass its capability for rhizodegradation. BTEX compounds can serve as primary electron donor for a wide variety of soil bacteria [Gemida et al, 2002], furthering the possibility of bacterially-accelerated rhizodegradation. Case studies and a study on high levels of PAHs on contaminated soils from a manufactured gas plant suggest that rhizodegradation and phytosequestration (and possibly microbially-enhanced forms of these sub mechanisms) appear to be operating in how switchgrass and little bluestem remove polycyclic aromatic hydrocarbons.

The literature search suggests that implementation of little bluestem and switchgrass in phytoremediative systems would likely result in successful remediation of PAHs (if present) over the Edwards Aquifer. Since TCEQ Edwards Aquifer Rules currently prohibit new industrial activity, any PAHs generated likely occur from point sources related to existing industrial, mining or military complex activities, or from nonpoint sources related to automobiles (urban area traffic and cross-country highways).

5. Conclusions

Although there is a relative paucity of data on little bluestem's ability to retain sediments onsite, there exists considerable data on switchgrass' ability to retain sediments. Switchgrass hedges are effective in removing sediments from surface runoff. Most of the sediment that is trapped above the switchgrass hedge is deposited because it has sufficient settling time in the ponded flow - not because it was unable to pass through the voids in the grass. This ponding action, rather than a filtration action, is counter to the TCEQ's understanding of sediments management as exemplified in its Edwards Aquifer Technical Guidance Manual. The TCEQ and/or the community it regulates is familiar with the traditional approach of allowing erosion, then dealing with the sediment that is generated by that erosion. TCEQ and the regulated community may be unfamiliar with the approach of preventing erosion and keeping sediments onsite via use of switchgrass hedges.

Lack of data pertaining specifically to Texas may have contributed to TCEQ's former unfamiliarity with phytotechnology in general and with phytostabilization in particular, which is defined as (1) immobilization of a contaminant in soil through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone of plants, and (2) the use of plants and plant roots to prevent contaminant migration via wind and water erosion, leaching, and soil dispersion [U.S. Environmental Protection Agency, 2000]. The term phytostabilization justifiably describes the use of plants to prevent sediment transport.

To this author's knowledge, phytotechnology of any type has not been widely implemented on locations over the Edwards Aquifer. However, TCEQ's February 2008 InterOffice Memorandum states clearly that the agency's remediation leadership members agree that the Interstate Technology and Regulatory Council's document Phytotechnology Technical and Regulatory Guidance Document is appropriate and that they commit to using the document to the maximum extent feasible. There may be a time lag before this remediation directive is widely understood and implemented by TCEQ staff.

Data suggesting that coarser soil particles are preferentially retained by switchgrass hedges allows transference of information gathered from other locations to locations over the Edwards Aquifer area for purposes of preventing sediment transport into the sensitive aquifer. Site-specific soil assessments could be performed to determine if particular Edwards Aquifer soils contain particles that fall within the range treatable by switchgrass hedges.

PAH-phytoremediative capabilities of switchgrass and of little bluestem have been identified and case studies dealing with PAH phytoremediation performed by both of these species demonstrate the species' PAH-phytoremediative capabilities. Since TCEQ Edwards Aquifer Rules currently prohibit new industrial activity, any PAHs generated over the aquifer likely occurs from existing point sources (e.g., manufacturing or military facilities) or from nonpoint sources related to automobiles (e.g., highways).

References

Alkorta, Itziar, Garbisu, Carlos, 2001. Phytoremediation of organic contaminants in soils. Bioresource Technology 79, 273-276.

April, Wayne and Sims, Ronald C., 1990. Evaluation of the Use of Prairie Grasses for Stimulating Polycyclic Aromatic Hydrocarbon Treatment in Soil. Chemosphere Vol. 20 Nos. 1-2, 253-265.

Cofield, Naressa, Schwab, A. Paul, and Banks, M. Katherine, 2007. Phytoremediation of Polycyclic Aromatic Hydrocarbons in Soil: Part I. Dissipation of Target Contaminants. International Journal of Phytoremediation 9:5, 355-370.

Cunningham, Scott D., Anderson, Todd A., Schwab, A. Paul, and Hsu, F.C., 1996. Phytoremediation of Soils Contaminated with Organic Pollutants. Advances in Agronomy Volume 56, 56-114.

Dabney, Seth M., Wilson, Glenn V., and McGregor, Keith C., 2012. Runoff Through and Upslope of Contour Switchgrass Hedges. Soil Science Society of America Journal Volume 76 Number 1, 210-219.

Dunn, G.H., and Dabney, S.M., 1996. Modulus of Elasticity and Moment of Inertia of Grass Hedge Stems. Transactions of the American Society of Agricultural Engineers Volume 39(3), 947–952.

Gemida, J.J., Frick, C.M., and Farrell, R.E., 2002. Developments in Soil Science Volume 28B, 169-186.

Geza, Mengistu, Barfield, B.J., Huhnke, R.L., Stoecker, A., Storm, D.E., and Stevens, E.W., 2009. Comparison of Targeted Replacement and Vegetative Filter Strips for Sediment Control and Cost Effectiveness. Journal of Water Resources Planning and Management American Society of Civil Engineers Volume 5, 406-409.

Gilley, J.E., Eghball, B., Kramer, L.A., and Moorman, T.B., 2000. Narrow Grass Hedge Effects on Runoff and Soil Loss. Journal of Soil and Water Conservation 55, 2, 190-196.

Gould, Frank W., 1978. Common Texas Grasses: An Illustrated Guide. Texas A & M University Press.

Hutchinson, S.L., Schwab, A.P., and Banks, M.K., 2003. Biodegradation of Petroleum Hydrocarbons in the Rhizosphere, in Phytoremediation Transformation and Control of Contaminants edited by McCutcheon and Schnoor, John Wiley & Sons.

Kemper, Doral, Dabney, Seth, Kramer, Larry, Dominick, Darrel, and Keep, Tom, 1992. Hedging against Erosion. Journal of Soil and Water Conservation Volume 4, 284-288.

Interstate Technology and Guidance Regulatory Council, 2009. Phytotechnology Technical and Regulatory Guidance and Decision Trees, Revised February 2009, Prepared by The Interstate Technology & Regulatory Council Phytotechnologies Team ,Tech Reg Update.

Lee, H-H., Isenhart, T.M, Schultz, R.C., and Mickelson, S.K., 1999. Nutrient and sediment removal by switchgrass and cool-season grass filter strips in Central Iowa, USA. Agroforestry System 44, 121-132.

L.B.G. Guyton Associates in association with BioWest, Inc., Espey Associates, Inc. and URS Corporation, 2004. Evaluation of Augmentation Methodologies in Support of In-Situ Refugia at Comal and San Marcos Springs, Texas, prepared for the Edwards Aquifer Authority.

McMahon, M.J., Kofranek, Anton M., Rubatzky, Vincent E., 2007. Hartmann's Plant Science Growth, Development, and Utilization of Cultivated Plants, Fourth Edition, Pearson Prentice Hall.

Meyer, L.D., Dabney, S.M., and Harmon, W.C., 1995. Sediment-Trapping Effectiveness of Stiff-Grass Hedges. Transactions of the American Society of Agricultural Engineers Vol. 38(3), 809 – 815.

O'Connor, Rod, 1977. Fundamentals of Chemistry, Second Edition, Harper & Row Publishers.

Pradhan, S.P., Conrad, J.R., Paterek, J.R., and Srivastava, V.J., 1998. Potential of Phytoremediation for Treatment of PAHS in Soil at MGP Sites. Journal of Soil Contamination 7:4, 467-480.

Rachman, A., Anderson, S.H., Gantzer, C.J., and Alberts, E.E., 2004. Soil Hydraulic Properties Influenced by Stiff-Stemmed Grass Hedge Systems. Soil Science Society of America Journal 68,1386-1393.

Rankins, A., Shaw, D.R., and Boyette, M., 2001. Perennial Grass Filter Strips for Reducing Herbicide Losses in Runoff. Weed Science Volume 49 No. 5, 647 – 651.

Salt, D.E., Smith, R.D., and Raskin, I., 1998. Phytoremediation. Annual Review of Plant Physiology and Plant Molecular Biology 49, 643-668.

Texas Commission on Environmental Quality, 2004. Texas Administrative Code Title 30, Part1 Chapter 213.

Texas Commission on Environmental Quality, 2005. Complying with the Edwards Aquifer Rules Technical Guidance on Best Management Practices RG-348 revised July 2005.

Texas Water Commission, 1993. Underground Water Conservation Districts Report to the 73rd Legislature GP93-05.

Todd Engineers, 2004. Analysis of Recharge and Recirculation Edwards Aquifer Phase 1, prepared for Edwards Aquifer Authority.

Tomer, M.D., Moorman, T.B., Kovar, J.L., James, D.E., and Burkart, M.R., 2007. Spatial patterns of sediment and phosphorous in a riparian buffer in western Iowa. Journal of Soil and Water Conservation 62,5, 329-338.

U. S. Environmental Protection Agency, 2000. Introduction to Phytoremediation. U.S. Environmental Protection Agency National Risk Management Research Laboratory Office of Research and Development EPA/600/R-99/107.

U.S. Environmental Protection Agency, 2011. U.S. EPA Contaminated Site Cleanup Information (CLU-IN) Phytotechnology Project Profiles. http://www.cluin.org/products

U.S. Geological Survey, 2004. Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas. United States Geological Survey Scientific Investigations Report 2004-5041.

Appendix A

The TCEQ February 2008 Interoffice Memorandum is pasted below

To:	Dan Eden, Deputy Director Office of Permitting, Remediation and Registration	Date:	February , 2008
Thru:	Alan R. Batcheller, P.G., Director Remediation Division		
From:	Jay Carsten, Manager Environmental Cleanup Section II, Remediation Division		
Subject:	Request for Concurrence for the Interstate Technology and Regulatory Council (ITRC) documents		

Gary Beyer, Project Manager in the Environmental Cleanup Section II represents the TCEQ as the State Point-of-Contact for the ITRC. The ITRC is composed of industry, academic, and government representatives, addresses issues related to implementation of innovative remediation technology at both private and military installations. The role of TCEQ's participant is to promote training and implementation of innovative technologies and develop models for overcoming regulatory barriers to effective remediation implementation.

To this end ITRC teams have produced technical and regulatory guidelines which shows how to avoid regulatory pitfalls which could cost much money and time for owners and operators of public, military, and private hazardous waste facilities. These documents also provides guidance to regulators and consultants on designing sampling and remediation programs that are both cost effective and protective of public health and the environment. A list of documents proposed for concurrence and adoption are included with this memo. The State of Texas has previously concurred on nine ITRC documents.

A draft letter and instructions concerning the ITRC concurrence process are included with this memo for your consideration. The purpose of the concurrence process is to gain state commitment to use the ITRC document which provides predictability for parties wanting to use an innovative technology in an ITRC state. There are three levels of concurrence as follows:

Level A - We concur. We agree that the requirements/guidelines are appropriate and commit to using them to the maximum extent feasible.

Level B - We agree that the requirements/guidelines are appropriate; however, we cannot commit to Level A concurrence for this reason: (state response)

Level C - We do not concur with the requirements/guidelines for this reason: (state response)

Following is a list of documents recommended for concurrence and the recommended level that concurrence be granted:

Document Name Recommended Reviewer Concurrence Level

Munitions Response Historical Records Review Level A Kera Bell

Geophysical Prove-Outs for Munitions Response Projects Level A Kera Bell

Environmental Management at Operating Outdoor

Small Arms Firing Ranges Level A Gary Beyer

Planning and Promoting Ecological Reuse of Remediated Sites Level A Ellie Wehner

Phytotechnology Technical and Regulatory Guidance Document Level A Ellie Wehner

The Use of Direct Push Well Technology for Long-term

Environmental Monitoring in Groundwater Investigation Level A Sue Rogers

Strategies for Monitoring the Performance of DNAPL Source

Zone Remedies, August 2004. Level A Sue Rogers

The reviewers of these documents are members of their respective ITRC teams and participated in the creation of these documents.

Additional information on the concurrence process is included as an attachment to this memo. Also the ITRC State Point of Contact, Gary Beyer is available for consultation.

If you have any questions regarding this matter, please contact me at 239-5186.

** This concludes the TCEQ Interoffice Memorandum**